THINGS of science

COPPER BASIN GEOLOGY

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COPPER BASIN GEOLOGY

Copper is familiar to all of us. It is one of the important metals which we depend upon in our daily lives, especially for carrying electricity to our homes for the many conveniences we enjoy. The metal has been serving us since its discovery by the Armenians more than 6,000 years ago and is the first base metal used by man for making tools, containers and other objects. Early metal workers later learned to mix copper with tin to make the much harder bronze and with zinc to form brass, two alloys well known to us.

Most of the copper today is extracted from pyrite or chalcopyrite, an ore rich in copper. Pyrite is a common ore found in many regions of the world, but the largest producer of copper is the United States. Many copper mines exist in this country, including the Copperhill Mining Operations in the Tennessee Copper Basin, Ducktown, where your specimens were collected.

With these materials you will be able to understand something about the nature of the Copper Basin area and the mining and extraction of copper.

First identify your specimens which

are packaged in three bags, the first containing three items, the second two, and the third one.

The specimens in the first bag are:

GOSSAN—Brownish yellow or rust-colored amorphous substance; porous decomposed rock; sometimes called iron hat.

SLAG—Dark brown to black hard amorphous mass; sometimes dark gray; contains traces of air bubbles formed in cooling.

QUARTZ—White, opaque mineral; hard and brittle; silicon dioxide.

Specimens in second bag:

PYRITE—Pale brass yellow; crystals sparkle in light; hard; consists mainly of iron sulfide; often called Fool's Gold.

IRON SINTER—Coarse lump of iron ore; black with irregular holes and projections; brittle; formed by roasting ore particles at high temperature.

Third bag:

SHOT COPPER—One or more small pieces of reddish brown irregular metal; color is similar to copper penny; dull surface.

THE COPPER BASIN

The Tennessee Copper Basin is located in the extreme southeastern corner of Tennessee. It occupies a basin-like posi-

tion bounded by mountains 4,200 feet high. The Basin itself is on a plateau having an average altitude of 1,600 feet.

In 1843 copper-rich pyrite was discovered in the Basin and since then, for more than a century, copper has been mined in this area of Ducktown (see cover).

The mining of copper is done in underground mines. However, the central area of the basin covering about 7,000 acres is almost completely bare, although the region rimming the basin is covered with grass, colorful flowers and many green trees during the spring, summer and fall. This unusual landscape is the result of early mining operations that damaged the vegetation and top soil during the 50-year period prior to 1904.

During those years, to extract the copper, pyrite was roasted in large heaps of alternate layers of wood and ore. Pyrite contains a high percentage of sulfur and thus huge clouds of destructive sulfurous gases were released during the process.

As mining activity increased, so did the demand for wood, as fuel, and timber within hauling distance was cut indiscriminately. With tons of sulfur dioxide gas descending upon the remaining plant life combined with the activity of the sun,

rain and wind, the vegetation eventually was completely destroyed, and the central area no longer suitable for plant life, became denuded.

The deposits in the Copper Basin are mixed sulfides of iron, copper and zinc, and early mining efforts were devoted to the extraction of copper. As efforts were intensified to extract copper at minimum cost, no concern for environmental damage was shown. Thus, by 1878 approximately 50 square miles of the basin had been stripped of trees to furnish fuel for the extraction of the metal or smelting operations. Numerous companies, lacking in sound financial management, plundered the basin without regard to the destruction they were causing to the surrounding area.

The methods of mining have since been greatly improved and efforts are being made to reverse the erosive processes that were common to the Copper Basin for a period of nearly 50 years.

COPPER MINING

The materials in your unit, pyrite, iron, sinter, quartz, slag and shot copper are all a part of the copper extraction process. Gossan does not play a role in copper refining, but it usually indicates the presence of iron sulfide deposits

beneath it.

Let us examine the specimens and observe their properties, noting how each is related to the production of copper metal.

PYRITE

Experiment 1. Examine your specimen of pyrite, noticing the sparkling brass yellow crystals contained in the ore. Because pyrite at one time was often mistaken for gold, it is known as Fool's Gold.

Pyrite is composed primarily of iron sulfide, FeS_2. It is the most common sulfide mineral and occurs in rocks of all ages. In the United States it is found in New Jersey, Colorado, Tennessee, Wisconsin, Georgia, Massachusetts, Virginia and New York. Pyrite containing a high percentage of copper is known as chalcopyrite, $CuFeS_2$. Pyrite and chalcopyrite both have a brass-yellow luster and are often mistaken for each other. Ordinary pyrite also contains copper, but a much smaller amount. Pyrites may also contain such metals as zinc, tin and cobalt.

One way to distinguish between pyrite and chalcopyrite is by the color of their streaks, a test used by geologists. Pyrite produces a greenish to brownish black streak while chalcopyrite makes a greenish black streak. The streak test is made

by scratching a ceramic material, known as a streak plate, with the edge of the rock being tested.

Experiment 2. If you have a streak plate rub your pyrite specimen across it and note the color of the streak. If a streak plate is not available, the broken surface of a plate or saucer may be used as a substitute.

What color streak do you obtain?

The streak is produced by the color of the powdered mineral. Therefore, the color of the ore may also be observed by placing its finely ground powder on a background of white paper.

The pyrite in your unit contains only a very small percentage of copper since the copper-rich ore from the mines has been depleted by years of mining.

Experiment 3. Some minerals break along a definite plane. This is referred to as cleavage. Break your specimen of pyrite cautiously by lightly tapping it with a hammer. Note that it has no cleavage, but breaks into irregular pieces.

Experiment 4. Another physical characteristic of a mineral is its hardness. In the scale of hardness of 1 to 10 used by geologists, pyrite ranks about 6 to 6.5.

Mohs scale of hardness by which the hardness of a mineral is determined is as follows:

1. talc
2. gypsum
3. calcite
4. fluorite
5. apatite
6. orthoclase
7. quartz
8. topaz
9. corundum
10. diamond

The softest is talc and the hardest diamond. From the above, you can see that its hardness is just below that of quartz.

Take a small piece of the pyrite into a darkened room and strike it with a steel hammer. Do you see sparks? The impact of the hard steel against the pyrite releases energy, causing sparks.

Experiment 5. The pyrite specimen in your unit more than likely contains pyrrhotite, another sulfide of iron. Pyrrhotite is also bronze yellow in color, but it is slightly magnetic distinguishing it from pyrite. Check your specimen with a magnet to determine whether pyrrhotite is present.

Pyrrhotite produces a black streak. Nickel, cobalt, manganese and copper are common impurities in pyrrhotite. It is often reddish bronze-yellow in color,

tarnishing to a brown.

To mine the ore at the Copperhill Operations, the rock is first drilled and blasted to obtain the pyrite which is then loaded and hauled away to be crushed. After preliminary crushing, the ore is further crushed in revolving rod and ball mills. During this process water is added to the crushed ore to produce a pulp. The pulp is ground to a specified fineness necessary to free the minerals.

After the ore has been finely crushed, chemical reagents are added to it and the mixture is moved into flotation machines. During the first step, "bulk flotation," air is injected upward into the mixture forming a heavy froth that rises to the surface carrying grains of the ore with it. The ore, which resists wetting, is removed with the froth while the waste rock or gangue falls to the bottom. Gangue consists of the minerals and rock material mined with the ore and commonly contains such materials as quartz, calcite, feldspar and rock of various types.

The ore, removed from the worthless rock, is then processed to concentrate and separate the sulfide minerals of copper, iron and zinc.

From the mill the copper concentrate goes to the smelter where it is treated in a roaster to remove part of the sulfur,

and then melted in a huge reverberatory furnace, so named because its heat is reflected from the roof and walls. A suitable flux, such as limestone, is added to facilitate the separation of impurities which fuse with it to form slag.

Two layers of liquid are formed during this process, a molten concentrate called matte below, and the lighter slag on top. The slag is skimmed off into pots and transferred back to the furnace where some residual copper is settled out of it. The furnace slag is granulated by pouring it into a stream of water and then sold as an ingredient for cement.

The matte, consisting mostly of copper sulfides, is tapped or drawn out of the furnace into slag-lined cast iron pots. The hot matte is then passed into a converter through which pressurized air is blown. In this way sulfur and sulfur dioxide are removed as gases and sent into the acid plant for use in producing sulfuric acid. Any other impurities such as iron are oxidized as a result of the heat generated in the process and combine with silica to form slag.

Air is blown over the copper sulfide continuously until all the sulfur has been removed. As the molten copper cools, escaping gases cause the surface to acquire a rough, bubbly appearance and

the product now is called blister copper. The blister copper, more than 99% pure is solidified in either of two ways. It may be formed into 2,000-pound cakes or the molten blister copper may be poured into water to produce pellets called shot copper like the specimen in your unit.

SHOT COPPER

Experiment 6. Examine your specimen of shot copper. Note the irregular shape of the pellets formed by pouring the molten blister copper into water.

Note its color. Is it similar to that of a copper penny?

Experiment 7. Copper is a malleable metal and can be shaped by beating with a hammer. Place a piece of the shot copper on a solid base, such as a block of hard wood, and hammer it. Does it flatten out? See how thin you can hammer the piece. Bend it. You will find that it is soft and flexible.

Many objects including bowls and trays are made of hammered copper.

Copper is also a ductile metal and can be drawn into very fine wires, as thin as 1/1000 inch in diameter.

The metal is a good conductor of electricity and most of the copper manufactured is used for electrical purposes,

primarily wiring. Another very useful property of copper is that it is highly corrosion resistant.

With long exposure to the air, copper or copper containing alloys acquire a green colored protective coating, known as patina. You may have observed the green coloring on bronze statues. Once covered with patina, further corrosion of the metal is prevented, making it a very durable material. Probably the most famous "green" statue is the Statue of Liberty.

Have you noticed pots and pans with copper bottoms? Copper is used for this purpose because it is a good conductor of heat. This property combined with its corrosion resistance makes it useful for heat exchangers of many kinds including tubes for cooling systems, hot water cylinders and distilling units in chemical plants.

Experiment 8. Look around you and find out in what other ways copper is used, such as copper gutters on houses, ornamental metal work, and numerous automobile parts.

SLAG

Experiment 9. Slag is a by-product of copper manufacture. Look at your specimen of slag, noting its color, structure and hardness.

All iron ores, including pyrite, contain foreign materials, usually silicates, collectively called gangue. Limestone, composed mostly of calcium carbonate ($CaCO_3$), may be added to the ore as a flux to react with the gangue to form an easily fused slag. The slag separates from the molten ore and floats on top of it.

$CaCO_3$	$\rightarrow$	CaO	$+$	CO_2
limestone		lime		carbon dioxide

CaO	$+$	SiO_2	$\rightarrow$	$CaSiO_3$
flux		gangue		slag (calcium silicate)

From the above you can see that slag is composed principally of calcium silicate. It is an amorphous substance lacking any definite crystalline structure.

Experiment 10. Notice how hard it is. This makes it useful as material for building roads and in the manufacture of wallboard in addition to its use as an ingredient for cement. It is also ground and used for improving soils.

IRON SINTER

Pyrite from which the copper is extracted contains a high percentage of iron which is separated as a sulfide during the refining process. When ores are roasted

at high temperatures, sintering may occur. This process partially melts the fine particles of ore causing them to fuse together and form coarse lumps. These lumps of ore, iron sinter, may be placed in a blast furnace and raised to a high temperature to purify the metal.

Iron sinter produced at the Copperhill Operations is shipped to Birmingham, Ala., for processing to extract metallic iron.

Experiment 11. Note the porous structure of your specimen of iron sinter and its dark color. Observe how hard it is. It has no definite crystalline characteristics.

The specimen of iron sinter in your unit is a high-grade iron oxide product containing 68-70% iron. Take a magnet and see if it is attracted to it.

Apply the magnet to your piece of slag. Is it magnetic? If you should confuse the slag and iron sinter specimens because of their somewhat similar appearance how would you check to see which is which?

QUARTZ

Quartz is frequently present in areas where metal ores such as pyrite are found and is abundant in the Copper Basin region.

Quartz is the most common of all minerals and has a large number of distinct varieties and a wider range of differences between them than any other mineral.

Nearly all the varieties of quartz may be included in one of two groups: those that are crystalline and those that are massive or without definite crystalline structure visible to the naked eye. Under high magnification, the massive varieties will show crystalline structure.

Experiment 12. Observe your quartz specimen carefully noting its lack of luster, its color and structure.

Your specimen is a massive, milky quartz which often forms large veins in other rocks and is frequently gold bearing.

Quartz is chemically silicon dioxide or SiO_2 and in its pure crystalline form is colorless and transparent. However, various impurities may impart a variety of colors to it. Quartz sand is an example of the crystalline form of this mineral.

Experiment 13. Examine your quartz with a hand lens. Do you see minute glassy crystals that sparkle in the light on its surface? These are tiny grains of crystalline quartz.

Quartz has a hardness of 7 and is used as an abrasive for polishing surfaces,

such as sandpaper.

As mentioned earlier, in the early mining operations copper-bearing ore was roasted in large heaps of alternate layers of wood and ore. By intermingling small amounts of quartz in these stacks, the quartz served as a flux causing the impurities to melt at lower temperatures. The impurities floated away, leaving a higher grade of ore concentrate.

Experiment 14. Can you scratch a penny with the quartz? If so, this indicates quartz is harder than copper. Can you scratch the iron sinter or slag with the quartz?

Experiment 15. Break the quartz, noting that it is brittle and that it shows no cleavage.

GOSSAN

Gossan is an iron-containing rock which sometimes forms a superficial cover over pyrite and other sulfide deposits through the effects of weathering.

It consists principally of hydrated iron oxide, a product resulting from the oxidation and removal or leaching away of sulfur, copper and other elements from the original rock material. Gossan is sometimes called iron hat.

While there are no important uses for this mineral, gossan is usually an indi-

cation of the presence of iron sulfide deposits below. Gossan can be of great value to geologists searching for ores because it gives a clue to the type of underlying sulfide materials, whether they contain copper, zinc, silver and other valuable metals or only pyrite.

Experiment 16. Note the reddish brown color of gossan and its porous structure. The color is due chiefly to the rust-colored iron oxide.

Its pores were formed by the leaching away of the soluble components of the original rock. Examine the gossan with a magnifying glass. Can you see the many irregular holes it contains? Note how they vary in size.

Place a few drops of water on the gossan. Note how quickly it is absorbed.

Experiment 17. Note the irregular structure of gossan and its lack of luster. Compare its appearance with that of pyrite.

Experiment 18. Geologists often find it important to determine the porosity, or amount of pore space in a rock.

You may wish to determine the porosity of your specimen of gossan. However, since the specimen is small, you will need fairly delicate instruments to perform this experiment.

Porosity can be defined as

$$P = \frac{W}{V} \times 100 \quad ,$$

where W is the weight in grams of water required to saturate the specimen; V, the total volume of the specimen, and P, the porosity expressed in percent of the total volume.

To find the approximate porosity of your specimen, first find the dry weight of the specimen in grams. Be sure your specimen is absolutely dry.

Place the gossan in water allowing it to soak in it for a short while to saturate it completely with the water. Then weigh it again.

Subtract the dry weight from the wet weight to determine the amount of water filling the pore spaces, or W.

Pour water into a container graduated in milliliters or cubic centimeters, sufficient to cover your specimen. Submerge the water-soaked gossan in the water noting the increase in water level. This will show the amount of water displaced by the specimen or its volume, V.

Substituting the amounts obtained in the above formula you can determine the percent of porosity.

For example, if the dry weight of the specimen is 20 grams and the wet weight is 23 grams, the amount of water in the

pores is 23 — 20 or 3 grams.

One cubic centimeter or one milliliter of water weighs one gram. Therefore 3 grams is equivalent to 3 milliliters (ml).

If the volume of the water displaced by a specimen (a larger specimen than your sample) is 10 ml, then

$$P = \frac{3 \text{ ml}}{10 \text{ ml}} \times 100 = 30\%$$

The value derived in this manner may be somewhat less than the true porosity because some of the interior pores may not be open to the outer surface of the rock.

POLLUTION CONTROL

Since 1905 continuing efforts have been made to minimize pollution in the Copper Basin area.

In 1907 the Tennessee Copper Company converted the sulfur and sulfur dioxide gases released during smelting into sulfuric acid instead of pouring the destructive gases into the atmosphere. Other improvements in manufacturing and extraction processes have been made through the years and methods for utilizing other by-products such as iron sinter and slag were devised.

The Tennessee Copper Company in a

joint effort with the Tennessee Valley Authority planted more than 1½ million pine seedlings since 1936 in order to reforest the denuded basin area.

An electric furnace capable of the total capture of sulfur dioxide discharged from the stack has now been installed replacing a reverberatory furnace, further reducing the contamination of the air.

With the cooperation of industries such as the Copperhill Operations much can be accomplished in reducing pollution and conserving our natural resources.

Mining ores is a complex operation involving many fields of study, including engineering, physics, chemistry, mathematics, and biology; and the earth sciences.

If you wish to study the subject further, the references below will be helpful.

Chemistry textbooks.

Geology textbooks.

Chemical Technology, An Encyclopedic Treatment, Vol. 3, Metals and Ores, Based upon a work originally devised by the late Dr. J. F. von Oss., Barnes & Noble, Inc., New York.

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Appreciation is expressed to Dr. W. W. Wyatt, University of Tennessee, Knoxville, Tenn., for his cooperation in preparing this unit and for permission to quote from the following publications: *The TCC Story,* Tennessee Copper Company Division, Copperhill, Tenn., 1966 (now the Copperhill Operations, Cities Service Co.,); speech by S. L. Norwood, Aug. 19, 1971; Cities Service Co., Annual Report, 1971.

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42

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